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ENHANCED AIR TASKING ORDER
OPTIMIZATION MODEL

by

Kevin R. Crawford

September 1994

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ENHANCED AIR TASKING ORDER OPTIMIZATION MODEL

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ABSTRACT

This thesis is an enhancement to the Air Tasking Order (ATO) Optimization Model, a linear integer optimization model that seeks to match the best air assets against the highest priority targets. The ATO Optimization Model was written as a 1993 Master's Thesis to help the Joint Forces Air Component Commander in wargames rapidly produce an ATO. The model was used in the global wargame SEACON 93 but some difficulties were encountered. Asset utilization was restricted by the static structure of the model and attempts to coerce the model into doing dynamic scheduling were unsuccessful. Additionally, the model's implementation required the user to have unrealistically extensive knowledge of the software being used, DBASE IV and GAMS. This thesis addresses these difficulties. First, it explicitly incorporates the time dimension in the optimization model, thereby allowing multiple sorties per aircraft per day, something that was not allowed in the static model. Second, a graphical user interface has been built around the optimization model to alleviate the need for the user to have a strong background in database or optimization software. The enhanced model produces face-valid results that are readily usable within high-pressure, fast-paced environments, such as a global wargame.

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EXECUTIVE SUMMARY

In both the real world and wargames, an integral part of theater level warfare is the coordinated use of air assets against the enemy. This coordination is done by the Joint Forces Air Component Commander, or JFACC, in the form of an Air Tasking Order, or ATO. The ATO is an air plan of all the events required in strike planning. It assigns the air assets of the various warfare commanders to target strikes and support missions.

The slow, labor intensive and inefficient manual method of ATO production observed by Lt. Matthew Dolan during his experience tour at the Naval War College led to the creation of the Air Tasking Order (ATO) Optimization Model, a Naval Postgraduate School Master's Thesis. The ATO Optimization Model is a linear integer optimization model that seeks to find the best match of the available assets to targets and missions.

During SEACON 93 the Naval War College attempted to implement the ATO Optimization Model in a production wargame. While able to make effective use of the model, several difficulties were encountered.

Dolan's model is a static model, intended for use over a short duration, so it ignores the possibility of multiple sorties by the same aircraft. However in SEACON 93, the

model was used for planning a longer period (24 hours) and this omission was problematic.

The second difficulty in SEACON 93 with the original ATO model dealt with the construction of the DBASE IV databases and their subsequent inclusion in the optimizer input file. The process of extracting the database information into a usable input to the optimizer was very manpower intensive and required detailed knowledge of DBASE IV and GAMS. It was recognized that requiring the user to have a working knowledge of both database and optimization software could invalidate the usefulness of the ATO model.

The enhancements to the Dolan model center on the incorporation of a time dimension, changing it from a static model to a dynamic one. In the original model, time on top (TOT) was not a consideration. The demand for strike packages was specified by location only. Now, demand is specified by both time (TOT) and location. Additionally, by incorporating the time dimension aircraft are now considered available to fly multiple sorties in a day. The availability of aircraft in each period depends on previous decisions concerning the times when aircraft launch and return.

With these enhancements, planners in the JFACC cell will have a better feel for how assets are being utilized and will be better able to track the number of sorties available for add-on or contingency plans. In addition, sortie launch times are computed, which speeds up data entry by personnel on the game floor.

To alleviate the user's need for a strong understanding of a commercial database program and the GAMS optimization software, a user-friendly graphical interface was developed using Visual Basic for Windows. The interface provides easy to use data entry screens for inputting the required data, creates the input file needed for the optimization program with a "click" of the mouse, and reproduces the results of the model in several formats that are useful and informative for the game players.

I. INTRODUCTION

In both the real world and wargames, an integral part of theater level warfare is the coordinated use of air assets against the enemy. This coordination is done by the Joint Forces Air Component Commander, or JFACC, in the form of an Air Tasking Order, or ATO. The ATO is an air plan of all the events required in strike planning. It assigns the air assets of the various warfare commanders to target strikes and support missions.

In the fall of 1992, while on a Naval Postgraduate School experience tour, Lt. Matthew Dolan observed the ATO production during the SEACON 92 wargame at the Naval War College. The slow, labor intensive and inefficient manual method of ATO production he observed led to the creation of the Air Tasking Order (ATO) Optimization Model [Ref.1], a Naval Postgraduate School Master's Thesis. The ATO Optimization Model is a linear integer optimization model that seeks to find the best match of the available assets to targets and missions. The model requires the following data: launch site locations, type and number of aircraft or Tomahawk assets available at each launch site, asset ranges, refueling requirements, number of refuelings allowable per mission, target/mission identification and location, target/mission priority, target/mission types, strike packages and strike package preference.

During SEACON 93 the Naval War College was attempting to implement the ATO Optimization Model in a production wargame. While able to make effective use of the model, several difficulties were encountered.

Dolan's model is a static model, intended for use over a short duration, so it ignores the possibility of multiple sorties by the same aircraft. However in SEACON 93, the model was used for planning a longer period (24 hours) and this omission was problematic. An attempt to coerce the model into scheduling two sorties per aircraft by doubling the size of the available pool was unsuccessful because it led to simultaneous flights of more assets than really existed.

The second difficulty in SEACON 93 with the original ATO model dealt with the construction of the DBASE IV databases and their subsequent inclusion in the optimizer input file. The process of extracting the database information into a usable input to the optimizer was very manpower intensive and required detailed knowledge of DBASE IV and GAMS. It was recognized that requiring the user to have a working knowledge of both DBASE and GAMS could invalidate the usefulness of the ATO model.

This thesis presents two major enhancements to Dolan's ATO Optimization Model. First, it incorporates the time dimension and enables the user to model over any time period deemed necessary. Time on target (TOT) is a centerpiece of the model. Planners in the JFACC cell need the time dimension in order to have a better feel for how assets are being utilized and to track the number of sorties available for add-on or contingency plans. In addition, sortie launch times are computed in the enhanced model, which speeds up data entry by the personnel on the game floor.

The second enhancement is a user friendly graphical interface which provides for better understanding of the database structure and enables the user to construct a data file in the proper format for GAMS implementation. The user is able to import the optimized ATO schedule and produce flight schedules in several different formats for use by the various game players. The interface package surrounding the GAMS model is written in VISUAL BASIC for Windows.

II. FORMULATION

A. APPROACH

The purpose of the optimization model is to find the best match of the available assets to designated targets and missions, and to schedule launches so as to meet the required times on target (TOT). During data entry, discussed fully in Chapter II, targets and missions are grouped into different target/mission types. Each target/mission type has several different strike packages, consisting of different types and numbers of assets, that are capable of performing the mission. If multiple assets of a single type are required then these assets must all launch from the same site. This is called a single sourcing constraint and reflects the actual practice, whenever possible, of aircrews briefing a mission together and helps maintain flight integrity. The various strike packages are compared against the availability of the assets that make up the strike packages to meet the TOT. The model selects the most desirable strike packages (for a given target type) available and attempts to strike all targets. If there are insufficient assets to hit all targets the highest priority targets are struck first.

The enhancements to the Dolan model center on the incorporation of a time dimension, changing it from a static model to a dynamic one. In the original model, TOT was not a consideration. The demand for strike packages was specified by location only. Now, demand is specified by both time (TOT) and location. Additionally, by incorporating the time dimension, aircraft are available to fly multiple sorties in a day, an aspect that the original model did not allow. The time element is achieved in the following way:

- The 24 hour day is segmented into X number of periods, each period representing 24/X hours.
- Each target or mission is assigned a Time on Target (TOT), which is converted to the proper period (POT).
- The time, as measured in <u>periods</u>, required by a strike package to fly to the target, called the fly out time (FOT), and the total cycle time (CT), which includes the time required to fly to and from the target plus any on station time (ST) is computed.
- The period when the aircraft will have to launch, if assigned, is determined for each potential launch site and eligible asset, based on TOT and FOT.
- The availability of aircraft in each period depends on previous decisions concerning the time when aircraft launch and return.

Appendix A contains the GAMS source code of the model described in this chapter.

B. INDICES

The following indices are used to formulate the optimization model:

a	assets
i	sites
j	targets
m	target/mission types
n	strike packages
t	time periods

An example of the values over which these indices can range is:

$a \in$ {F-14, F-18, F-15, AV-8B, TLAM}
$i \in$ {AIRBASE-01, CV-65, DDG51}
$j \in$ {T-01, T-02, CAP-1, AEW-1, CAS-01}
$m \in$ {SAM, HBUNKER, CAP, AEW, CAS}
$n \in$ {PACKAGE-01, PACKAGE-02, PACKAGE-03)
$t \in$ {T1, T2, T3, T4, T5, T6}

The j index represents the actual targets and m represents the target/mission types. The n index represents the various strike packages consisting of assets from index a that are have been previously judged appropriate to use against the target types of index m. For example, a target which is of target type SAM could be assigned one package consisting of two A-6's and one EA-6B or a second package consisting of two F-15's and one EF-111. The t index represents the time, in periods, that an event will occur.

C. DECISION VARIABLES

The primary decision variables of the model are binary variables. These variables decide which strike package is assigned for each target or mission and which site provides the assets required in each strike package. The first set of binary variables are:

X_{jnt} = 1 if strike package n is assigned to target j arriving on top in period t.

= 0 if not.

The second set of binary variables are:

Y_{aij} = 1 if site i is authorized to provide asset a to target j

= 0 if not.

There are three other variables in the model. The first two are general integer variables:

Z_{aijt} = The quantity of asset a allocated from site i to strike target j launching in period t

QL_{ait} = The quantity of asset a at site i at the end of period t.

Variables Y and Z are both used to provide assets for targets or missions from a launch site. They are both needed because of the single sourcing constraint. Variable QL is needed to keep track of the inventory of assets at each launch site.

The last variable is an elastic variable for target non-assignment. It allows the target strike constraint to be violated at a cost that is entered as an input parameter. The elastic variables are:

E_j = 1 if target j is left unstruck

= 0 otherwise.

The cost of the elastic variables is prohibitively high, so that a target is left unstruck only if it is physically impossible to strike all targets at their designated TOT with the given assets. The model does not consider the possibility of striking at some time other than TOT, because of the ripple effect a change might have on subsequent sorties.

D. OBJECTIVE FUNCTION

The objective function of the model seeks to maximize the weighted sum of the selected targets to be struck and missions filled less a penalty for non-assignment. A small distance penalty is also included in the objective function to insure that the closest assets are used whenever multiple assets are available. The model assigns the most preferred strike package to each target and mission requested by comparing the commander's preferences with the capabilities of the assets and the requirement to meet the time on target (TOT):

$$MAXIMIZE \sum_{jnt} EPREF_{jn} X_{jnt} - \sum_{j} TPREF_{j} EPEN_{j} E_{j} - \sum_{aij} DPEN_{aij} Y_{aij}$$

where:

- $EPREF_{jn}$ = Preference value of the strike package
- $TPREF_{j}$ = Target preference value
- $EPEN_{j}$ = Elastic penalty for not striking the target
- $DPEN_{aij}$ = Penalty value for distance an asset must fly to reach a target.

EPREF and TPREF are parameters relating the preference values which the user inputs during data entry. Chapter III discusses these inputs. These parameters ensure that the model selects the "best" strike package and highest priority targets and missions. DEPN is a distance penalty that is computed using the range to the target and the combat radius of the aircraft chosen to strike said target.

E. CONSTRAINT EQUATIONS

1. Target Strike Constraints

The first set of constraints ensures that each target is struck at its assigned time on target or a penalty is assigned. The strike constraints are:

$$\sum_{n} \sum_{t:t=POT_j} X_{jnt} + E_j = 1 \ , \ \forall j.$$

Because X is a binary variable, this constraint ensures that either one strike package is assigned at the required time on target or a penalty is assessed.

2. Demand Constraints

The second set of constraints ensures that the demand for assets at each target at its assigned time on target is met. The demands constraints are:

$$\sum_{i} Z_{a,i,j,t-FOT_{a,i,j}} = \sum_{n} QTY_{a,j,n} X_{j,n,t} \ , \ \forall a, j, t$$

where: $QTY_{a,j,n}$ = The quantity of asset *a* in strike package *n* proposed for target j.

The variable Z uses time index $t\text{-}FOT_{aij}$

where: FOT_{aij} = the time required for asset *a* launching from site *i* to fly to target *j*, measured in periods.

The time index on Z must be adjusted because the time index on the X variable refers to the TOT period.

The left-hand-side of the constraint represents the quantity of an asset allocated from a launch site launching such that it will make its required time on target. The right-hand-side computes the demand for the asset as required by the chosen strike package.

3. Single Sourcing Constraints

The single sourcing constraints ensures that all aircraft for a given strike package against a given target come from the same launch site. They are not affected by the time index. The single sourcing constraints are:

$$\sum_{i} Y_{aij} \leq 1 \ , \ \forall a \neq \text{tanker}, \ \forall j.$$

An exception to the single source requirement is allowed for the tanker aircraft, because these missions do not require extensive pre-mission briefings and tanker assets from any site can perform the mission.

4. Supply Constraints

In the original model, the supply constraints were:

$$\sum_j Z_{aij} \le AVAIL_{ia} \ , \ \forall i, a$$

where: $AVAIL_{ia}$ = Quantity of assets of type a available at launch site i.

The parameter $AVAIL_{ia}$ was provided by the game players and as assets were used by the various strike packages this parameter ensured that assets were not tasked beyond their availability.

The enhanced model replaces the $AVAIL_{ia}$ parameter by the general integer variable QL_{ait}. The constraint can now be viewed as a traditional inventory balance constraint. The supply constraints are:

$$\sum_j Z_{a,i,j,t} + QL_{a,i,t} = QL_{a,i,t-1} + \sum_j Z_{a,i,j,t-CT_{aij}} \ , \ \forall a, i, t.$$

The left-hand-side of the constraint represents the assets that launch in period t from site i plus the assets that remain at the end of period t. The right-hand-side represents the assets remaining at the end of the previous period plus those aircraft returning in period t from earlier launches.

The Z variable on the right-hand-side uses time index $t\text{-}CT_{aij}$

where: CT_{aij} = The total time required to fly to the target or mission area, perform on-station duties, and fly back to site *i*, in periods.

The supply constraints assume that there is no loss of aircraft due to battle damage or mechanical malfunctions. It would be mathematically simple to include a deterministic aircraft attrition factor in the model, but it would then become extremely difficult to obtain integer solutions. The more realistic approach of stochastic losses is beyond the scope of this thesis.

5. Logical Constraints

The logical constraints are needed to ensure that the Z variables governing the allocation of assets are logically connected to the Y variables which govern the single sourcing. The logical constraints are :

$$Z_{aijt} \leq AVAIL_{ai} Y_{aij} \ , \ \forall \ a, i, j, t.$$

These constraints guarantee that the Y's and Z's are nonzero for the same values of *a, i, j*.

F. PENALTIES

1. Elastic Penalty

The elastic penalty is assessed only if a target or mission is not assigned a strike package. The penalty is multiplied by the relative importance of the mission or target. The goal of the model is to strike all targets and meet all mission requirements. The EPEN value is large enough that there is no situation where the objective function can benefit by deliberately neglecting a target or mission.

2. Distance Penalty

As the distance the assigned aircraft must fly increases, the distance penalty, DPEN, increases. Initially the penalty increases at a gradual rate, until it surpasses the aircraft's combat radius, entered as a parameter, $RANGE_a$. Beyond $RANGE_a$, the distance penalty increases more rapidly, reflecting the need for in-flight refueling and other factors such as crew fatigue and the greater possibility of aircraft malfunctions as flight time increases.

The distance penalty is computed as follows:

$$DPEN_{aij} = m1\left(\frac{DIST_{ij}}{RANGE_a}\right) \text{ if } DIST_{ij} \leq RANGE_a$$

where : m1 = proportionality constant of DPEN when refueling not required
$DIST_{ij}$ = Distance from site i to target j
$RANGE_a$ = Range of asset a.

When refueling is required the distance penalty is computed as follows:

$$DPEN_{aij} = 1 + m2\left(\frac{DIST_{ij} - RANGE_a}{RANGE_a}\right) \text{ if } RANGE_a \leq DIST_{ij}$$

where : m2 = proportionality constant of DPEN after refueling.

III. DATA REQUIREMENTS

The optimization program presented here requires a significant amount of data concerning the targets, launch sites and assets to be entered by the user. For wargames, much of the data is available in the game books. However some of the data requirements call on the user's general military background and familiarization with assets and tactics. Data available in the game books include:

- Target name
- Target latitude and longitude
- Target description
- Launch site name
- Launch site latitude and longitude
- Number and type of assets at launch site
- Asset range and speed
- Aircraft in-flight refueling capability
- Aircraft missions and weapons loadouts
- Amount of fuel a tanker has to give

Data not in the game books but required for the model are:

- Target identifier
- Target/mission type

- Targets to be struck
- Target preference
- Required time on target
- Launch site asset availability
- Amount of fuel taken per in-flight refueling
- Number of in-flight refuelings per mission
- Type and number of assets for each target type

This information is stored in databases and used to construct the GAMS input file. The databases and data entry is discussed in Chapter IV. The following sections further discuss the data requirements outlined above.

A. TARGET DATA

1. Target Identifier

The target identifier should reflect the geographic location of a particular target or give a description of the mission associated with it. For example, one enemy region may have the code name BRONX. Any target which is within the BRONX region is given an identifier B-#. A Combat Air Patrol mission is given the identifier CAP-#. Using this methodology all targets and missions have unique identifiers and the user can rapidly identify where a particular target is located or what the type of mission is. This identifier is used in the formulation of the model as the index j.

2. Target Latitude and Longitude

Target latitude and longitude is required to determine the distance from a potential launch site to the target. The model uses great circles to calculate distance.

3. Target/Mission Type

Determining the target/mission type for each target or mission is essential. The target descriptions found in the game book can help in this task. The user should try to limit the number of target/mission types to a manageable set. This aids in limiting the number of strike packages the user must create. In the real world, each target may be unique and require a unique strike package. However the limitations of a war game necessitate the grouping of targets with similar attributes into the same target/mission type.

The grouping of targets into target types should also be based on the user's judgment concerning appropriate strike packages. Targets that appear to be very different may require the same types of assets to successfully strike them, so they can use the same candidate strike packages.

Missions are also assigned a target/mission type. Airborne Early Warning (AEW) and Combat Air Patrol (CAP) are examples of missions that could be given types of AEW-1 and CAP-2. Missions such as a 2-plane CAP or a 4-plane CAP should be given unique types.

4. On-Station Time

Some missions require the assigned aircraft to stay airborne for a prescribed duration, called on-station time. Missions such as Airborne Early Warning (AEW), tanking and Combat Air Patrol (CAP) will have a required on-station time. This is a user defined entry.

5. Target Preference

When the targets to strike and missions to perform have been determined for a given run of the optimization model, they must be assigned preferences. Targets that must be hit and missions that must be performed receive a preference rating of 1. Less critical targets and missions receive a rating of 2 to 5 depending on their importance.

The model converts the preference rating to weights, so that the highest priority targets and missions have the heaviest weights in the objective function. The function is optimized if penalty values are minimized. The model will fill all higher weighted tasking, subject to availability, before those with a lesser value. If all the targets and missions are critical, they can all be given a preference rating of 1. This is not advised, however, because if there are insufficient assets for all tasking, then the user will have no direct influence on the choice of targets to strike and the model will select targets on the basis of distance, which is possibly a secondary issue in reality.

B. LAUNCH SITE DATA

Index *i* of the formulation represents the potential launch sites of assets within a strike package.

1. Site Position

Launch site latitude and longitude is required to determine the distance from a potential launch site to the target. This distance is used to compute the distance penalty for each asset. The model will attempt to select launch sites that minimize the distance penalty, assuming the availability requirement is met.

2. Asset Type and Availability

The type and number of assets at each launch site, at the start of a war game, is provided in the game book. The number of assets that are available for a given run of the optimization model will change as the game progresses. Therefore, the number of assets at a launch site is updated, as required, before each run of the model.

C. ASSET INFORMATION

1. Combat Radius or Range

This information is provided in the game book under Performance Characteristics. The combat radius represents the aircraft's unrefueled range. After in-flight refueling, the aircraft has its complete range available.

2. Speed

There are several aircraft speeds listed in the game book. The speed listed under Performance Characteristics represents the tactical speed. It is left to the user's discretion as to which speed is used.

3. Take

Take refers to the amount of fuel the aircraft will take on during an in-flight refueling. This is dependent on such factors as distance to target, capacity at the time of refueling, and time until recovery. This input parameter, represented by $TAKE_a$ in the model, is user defined and allows for the computation of a lower bound on the amount of gas that will be required for each run of the model.

4. Give

Give refers to the amount of gas the airborne tanker aircraft has to give to aircraft requiring in-flight refueling. The game book provides this information. This input is represented in the model by the parameter $GIVE_a$.

5. Number of In-Flight Refuelings

The number of times an aircraft can refuel during the course of a mission is limited by the user to account for aircrew fatigue and potential aircraft malfunctions as flight times increase. A judgment call is made when entering this data, which is represented in the model by the parameter $MAXFILLS_a$.

D. STRIKE PACKAGES

Section A of this chapter presented the concept of target/mission types. Each target/mission type is assigned from one (1) to three (3) candidate strike packages. Each strike package is composed of from one (1) to ten (10) different assets, which, as a group, can be considered necessary to successfully attack a target or complete a mission.

The strike packages can be a diverse mix of aircraft. The number of assets of each type can also vary. The model attempts to optimize the ATO by assigning the most preferred packages if the assets are available and within reasonable ranges.

Each of the strike packages for a given target type is assigned a preference rating. A rating of one (1) is given to the most preferred package and subsequent packages are rated from two (2) to five (5). If packages are considered equal they are given the same preference rating. Assuming that the assets in the packages are available, distance would then determine which package is preferred.

The distance penalties discussed in Chapter II have an effect on the preference ratings of candidate strike packages when used in the objective function. As outlined in Dolan, the parameters m1 and m2 effect the balance of the distance penalty to the strike package preference. The objective function of the model is designed so that a package that requires in-flight refueling to complete its mission loses one (1) preference rating. Thus, a candidate package that has a rating of two (2) and requires in-flight refueling is considered equally preferred to a package that has a rating of three (3) but does not require in-flight refueling. This fact must be considered when selecting the preference ratings of the candidate strike packages.

IV. USER INTERFACE

The ATO Optimization model requires significant target, launch site and asset information. This information was originally designed to be stored in any of a number of commercially available database or spreadsheet packages. To be able to input and effectively retrieve the necessary information for each GAMS run required more than a passing knowledge of the package chosen.

The data storage/retrieval program developed in this thesis has been designed such that with only a rudimentary knowledge of the Windows environment and database type programs, the user will be able to create the necessary databases needed by the model and also put that data into the format required by GAMS.

Appendix A contains a sample GAMS input file and Appendix B contains sample database files created with the interface described in this chapter.

A. GENERAL INTERFACE

On start-up, the user is informed that the data and GAMS files to be created will be written to the A drive and that a formatted 3.5 inch floppy disc must be inserted.

1. Keyboard/Mouse

All user interaction may be conducted using either the mouse or the keyboard. Keyboard users utilize the TAB key to advance through the data fields on each form.

2. Data Fields

Each form asks the user to provide data which is required by the ATO model. As discussed in the previous chapter, most data (number of assets, latitude, longitude, etc.) is provided to the user in the game books. The exact requirements of each form are discussed below.

3. Command Buttons

Command buttons enable the user to add and delete records, move forward and backward among the records, search for a specific record and exit the database. Databases which will be completely revamped for each game, such as the Target database have a command button to delete the entire database. Command buttons are actuated by either the mouse or the keyboard.

4. List Boxes

Several forms contain a list box adjacent to a data field. These list boxes provide the user with a listing of available choices for the field. Except where noted below, the user must select a choice offered in the list box.

B. MENUS

On start-up, the package provides the user with a menu selection bar found in many Windows applications.

1. File

Under the File menu selection the user choices are Make GAMS Input File, Import GAMS Output File, Print or Exit.

a. Make GAMS Input File

When this option is selected the program executes the code to search through the created databases and put the data in the format required by GAMS.

b. Import GAMS Output File

This option executes the code to import the optimized assignment made by the model.

c. Exit

This option closes all the database files and exits the program.

2. Databases

Selecting Databases presents the user with the choice of Input/Edit or View.

a. Input/Edit

This option allows the user to select any one of the six databases supported by the program or have all six displayed. These databases are:

- Period/Time Information
- Asset Data
- Launch Site Data
- Strike Package Data
- Target Data
- Hit List Data

When a database is selected, the associated form is displayed.

b. View

Selecting this option presents the user with a form to view the current data in the Asset, Launch Site, Target and Hit List databases. The user may also select Packages. This option only presents the Target/Mission Types which have been entered in the Strike Package database. The user selects the command button at the bottom of the screen for the desired database information.

c. Print

This option allows the user to print any or all of the following databases:

- Asset Data
- Launch Site Data
- Strike Package Data
- Target Data
- Hit List Data

All of the data contained in these databases is printed.

3. Guided Tour

Selecting Guided Tour presents the user with a choice of either Initial Input or Hit List Input.

a. Initial Input

This selection displays all the forms for the databases which will normally be built prior to the start of a game. The following database forms are presented in a cascade for the user:

- Strike Package Data
- Target Data
- Launch Site Data
- Asset Data

As the user finishes with a database, it can be closed and the form removed, reduced to an icon for later selection or, by selecting another form, the new selection becomes the active form.

b. Hit List Input

This selection displays the forms for those databases which will be created or most likely modified during each round of play. They are:

- Period/Time Information
- Strike Package Data
- Launch Site Data
- Hit List Data

4. Flight Schedules

Selecting Flight Schedules presents the user with a choice of Print by Launch Site (LT), Print by Launch Site (TOT), Print by Target, Edit and ATO Information.

a. *Print by Launch Site (LT)*

This selection prints the flight schedule suggested by the optimization model sorted by launch site and launch time. This format is most useful for data entry on the game floor.

b. *Print by Launch Site (TOT)*

This selection prints the suggested flight schedule sorted by launch site and time on target (TOT).

c. *Print by Target*

This selection prints the suggested flight schedule sorted by time on target (TOT). This format is most useful for the JFACC cell to evaluate the schedule the model has suggested.

d. *Edit*

This selection presents the user with a dialog box from which he chooses the file name of the schedule he would like to modify. The file names are SKED_LT.TXT, SKED_TOT.TXT and SKED_TOT.TXT. Changes made to these files do not modify the schedule suggested by the model or have any effect on the ATO information file.

e. Print ATO Information

Selecting Print ATO Information prints the file that was created based on the optimization model schedule. This file contains the following:

- A message declaring all targets have been assigned a strike package or lists the targets not assigned
- The end of period inventory at each launch site by asset
- Sortie totals at each launch site by asset
- Total sorties scheduled
- An estimate of the amount of fuel required for in-flight refueling

Appendix C contains flight schedules in the format mentioned above and the ATO Information printout.

C. DATABASE FORMS

As stated previously, only data which is required by the ATO Optimization model is solicited from the user. The following sections describe each database form, the data requested on the form.

1. Period/Time Information

This form requests the time information needed by the ATO model. The specific data requirement is:

- Number of periods in a 24 hour day

This requirement is a subjective input and the user makes his selection from the list provided on the form. The ATO model bases all its time calculations on the selected number. Figure 1. depicts the time period input form.

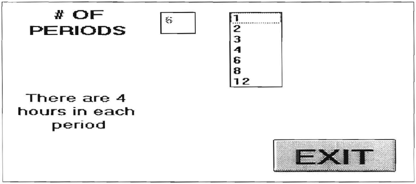

Figure 1. Time Period Input Form

2. Asset Database

The Asset database requires the following information:

- Asset name
- Combat radius (range)
- Speed
- Take
- Give (tankers only)
- Number of in-flight refuelings per mission

The asset name may be selected from the list provided or, if not on the list, typed in. Asset combat radius, speed and tanker give are provided in the game books. The amount of fuel received during inflight refueling and the number of inflight refuelings allowed during a mission are subjective inputs from the user as discussed in Chapter III. Figure 2 depicts the asset input form.

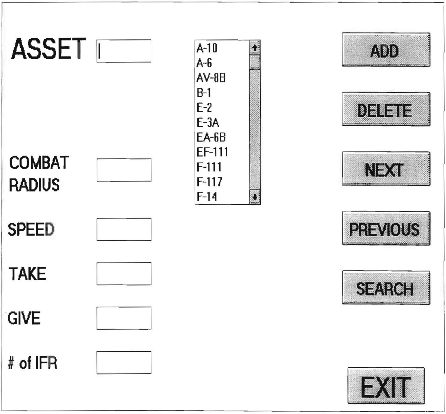

Figure 2. Asset Input Form

3. Launch Site Database

The Launch Site database contains the information needed about all potential asset launch sites. The database requires the following information:

- Launch site name
- Site latitude and longitude
- Type of assets available
- Number of each asset

All information required for this database is contained, initially, in the game books. The number of available assets will change throughout the game and will need to be updated prior to each GAMS run. The launch site name may be modified or abbreviated for ease of use. A single site can have up to ten (10) different types of assets operating from it. If there are more than ten different assets, a second launch site with a unique name but the same latitude and longitude can be used. Figure 3 depicts the launch site input form.

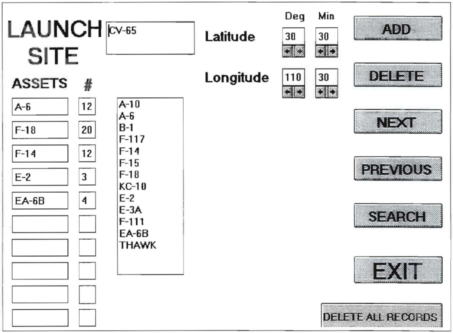

Figure 3. Launch Site Input Form

4. Target List Database

The Target List database contains the information needed on all targets. This database requires the following information:

- Target identifier
- Target name
- Target latitude and longitude in degrees and minutes
- Target type
- On-station time (if needed)

Target name and latitude and longitude are provided in the game book. Target identifier (Target ID) is user defined as discussed in Chapter III. Target type must be selected from the list of choices offered in the list box. This ensures that there is a strike package associated with this target type, otherwise a GAMS error would result. Figure 4 depicts the target input form.

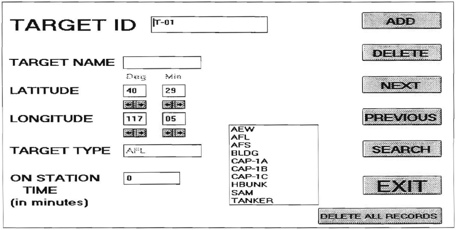

Figure 4. Target Input Form

This form appears when Initial Input is chosen. It is assumed that all potential targets are listed in the game book (or supplemental information). If new targets become available during the course of the game, selecting Databases, Target List from the menu allows the user to add new targets.

When the user selects the Search command button on the Target List form he is informed that the search is done using the target ID vice the target name.

5. **Strike Package Database**

The Strike Package database requires the following information:

- Target/Mission type
- Asset name
- How many of the selected asset to include in the package
- Package preference

As discussed in Chapter III target/mission type is used to categorize each target or mission into a manageable number of different classes. Examples of target/mission types include AIRFIELDS, SAM SITES, NAVAL BASES, POL STORAGE, COMBAT AIR PATROL (CAP), AIRBORNE EARLY WARNING (AEW), and TANKER. The user then builds up to three (3) different combinations of assets, called strike packages, with which to use against a particular target or for a mission.

For each package the user may select up to ten (10) different assets and chooses how many of each asset to include. The user then assigns a preference for the package, as discussed in Chapter III. The range is from 1 (highest or most preferred) to 5 (lowest or least preferred). Figure 5 depicts the strike package input form.

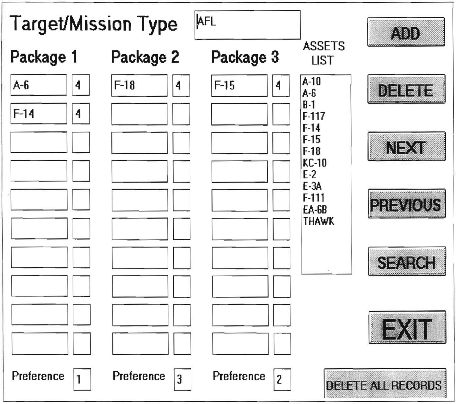

Figure 5. Strike Package Input Form

6. Hit List Database

The Hit List database contains information about the targets which the user desires to strike for a particular iteration of the GAMS program. The Hit List database requires the following data:

- Target ID
- Target preference
- Time on target

The target ID is used to identify the target and must be selected from the list provided on the form. The list contains all the targets that have been entered in the Target database.

The preference field is used to prioritize the targets as outlined in Chapter III. The highest priority target should be given a preference value of one (1) and the lowest a value of five (5). Time on target is entered in military time, i.e.. 04 hours 00 minutes, 23 hours 15 minutes. Figure 6 depicts the hit list input form.

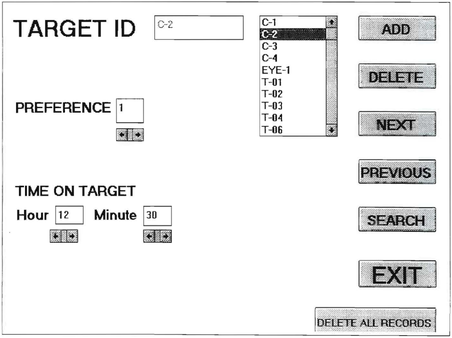

Figure 6. Hit List Input Form

V. RESULTS

A sample problem with 37 targets to be struck was run on an IBM compatible 486/50 computer with 64 megabytes of random access memory (RAM) using GAMS and XA. Eight, 12 and 24 period models were tested with optimality tolerances of .25, .10, .05 and .01. The results of these runs is discussed below.

Properly defining the time index is a critical aspect of the model. As discussed in Chapter II, the parameters CT (cycle time), FOT (fly out time) and ST (on-station time) are used to properly relate the X and Z variables and are critical in the demand and inventory constraints. The model uses integer values in units equal to the size of a time period for CT, with a minimum CT of 1. A cycle time of zero would imply that an asset could fly an infinite number of sorties in any given period. A non-integer cycle time cannot be accounted for within a model that discretizes time. FOT's are also assigned integer values greater than or equal to zero. ST's are integer values greater than or equal to zero.

A problem can arise when the FOT and ST parameters are rounded off to integers, because the model defines CT as

CT = (2 * FOT) + ST, with a minimum value of 1. This equation must be observed in the input data. Therefore, under certain conditions, the fly out time and/or on-station time parameters must be modified. Appendix A contains the GAMS code that is used to accomplish the required transformation of these parameters. These transformations ensure the X and Z variables are properly related and that the demand and inventory constraints are properly indexed.

A. MODEL OUTPUT

1. Run Time

As discussed above, the model was run varying the number of periods and the optimality tolerances. Table 1 contains the results of these runs. OPTCR is the optimality tolerance the user assigns in the GAMS code. When the model achieves its first solution that is within the set tolerance to the lowest available upper bound, it halts. The upper bounds are derived from linear programming relaxations of the integer program. The best integer solution column shows the value of the objective function of the model when the OPTCR is satisfied and an integer solution has been found.

TABLE 1. RUN RESULTS

# of Periods	OPTCR = .25 Run Time	LP Bound	Best Int Solution	OPTCR = .10 Run Time	LP Bound	Best Int Solution
8	0:00:24	178.1	146.5	0:45:13	164.9	149.9
12	0:00:11	178.3	149.9	1:03:25	161.1	146.5
24	0:00:15	178.1	147.8	1:44:26	160.1	145.5
	OPTCR = .05 Run Time	LP Bound	Best Int Solution	**OPTCR = .01** Run Time	LP Bound	Best Int Solution
8	0:24:23	162.8	155.0	> 10 hrs		
12	0:58:37	161.6	153.9	> 10 hrs		
24	1:07:17	160.8	153.1	> 10 hrs		

As Table 1 clearly demonstrates, increasing the number of periods and/or decreasing the optimality tolerance increases the run time of the model. All runs to within 1 percent of optimality were still running at the 10 hour mark and these runs were then terminated prior to completion due to the excessive run time. At termination, the model's best integer solution was the same as the 5 percent solution.

2. Model Assignment

As the optimality tolerance gets farther away from zero, the model has more flexibility in assignment and may select a suboptimal strike package for a particular mission, but only to the degree that the overall objective function satisfies the tolerance. This means that a target may be assigned a strike package which is not the most preferred. An example will help to illustrate this point.

When the 8 period model is solved to within 25 and 10 percent optimality there are seven targets, T-04, T-12, T-15, T-22, T-22, T-24, T-26 and T-27 that are assigned strike packages which are not the most preferred. When the same model is solved to within 5 percent optimality only targets T-12 and T-24 are assigned lesser preferred packages. The tradeoff in better assignment of strike packages comes at the expense of run time, i.e., a 25 percent optimal solution run time is 24 seconds and a 5 percent optimal solution run time is 24 minutes and 23 seconds.

3. Effect of Number of Periods

As discussed above, as the number of periods in the model increases, the run time increases. This result was anticipated because as the number of periods the model uses increases the number of sorties an asset can potentially fly also increases. This is due to the fact that as the number of hours in a period decreases, assets are ready for assignment sooner. Therefore, the model has more potential combinations of assignments to examine, thus increasing run time.

4. Flight Schedules

The output of the GAMS model is imported into the Windows interface and the assignments from the model are then written as flight schedules for use by either the JFACC cell or the game floor. The schedule for the JFACC cell lists the targets, launch site, assets assigned, the number of assets and the TOT. The schedule for the game floor presents the above information along with the launch time required and the target latitude and longitude. This facilitates rapid data entry on the floor.

5. ATO Information

The model also provides a file which includes information on the number of sorties flown from each launch site by asset, an approximation of the amount of fuel that will be required to fly the schedule, and an end-of-period inventory for each asset. Appendix C contains the flight schedules and ATO information printout for the 8 period run.

VI. CONCLUSIONS

The enhanced Air Tasking Order Optimization Model and user interface developed for this thesis rectifies the shortcomings that were encountered with the model's initial use at the Naval War College. First, the user can now successfully model a multiple period day, allowing assets to be used several times a day as they are in the real world. Second, it provides the user with a graphical user interface which is easy to manipulate for data entry, constructing the GAMS file needed by the optimization model and producing output that assists the players both in the JFACC cell and the game floor. This interface eliminates the need for the user to be more than passingly familiar with GAMS or skilled at the use of a commercial database program.

Originally, the optimization model was developed to help allow the JFACC cell of a wargame to rapidly produce a flyable ATO and not slow the pace of the wargame because of the time consuming process producing such an ATO may entail. The enhanced model successfully produces a flyable ATO in much less time than the manual method and with an efficient use of assets. Additionally, the enhanced model presents the user with an end-of-period inventory which can aid in reassigning assets if the JFACC deems changes to the suggested schedule are necessary.

A. RECOMMENDATIONS

The results presented in Chapter V suggest several recommendations in the implementation of the model. First, using an 8 or 12 period day should provide sufficient numbers of sorties per aircraft to fly most ATOs. Using a 24 period day may cause an unacceptable run time due to the size of the model or the optimality tolerance being used. Additionally, 2 or 3 hours per period can mask the affects of real world variation in fly out time, on-station time and rearm and refuel time without affecting the feasibility of the solution. Second, modifying the optimality tolerance to a value closer to zero, while potentially producing a "better" ATO, significantly increases run time. As the size of the model and number of periods increases, the model will take longer to solve. A "first cut" using .25 OPTCR should provide the user with a good ATO rapidly. If time allows, decreasing OPTCR to .05 and rerunning the model may produce a better ATO.

B. REFINEMENTS

The current model allows multiple sorties in a day but is restricted to a single sortie per period. If the period length is long in comparison to sortie length, this restricts the use of assets. Further work can be done to allow multiple sorties in a given period.

Time required for in-flight refueling and to refuel and rearm aircraft after landing are presently not incorporated in the calculations of mission time. Incorporating these would add further fidelity to total mission time.

C. FUTURE PROJECTS

There are several potential projects that can be pursued with this model. First would be a program that uses the weapons versus target data found in the Joint Munitions Effectiveness Manual (JMEM) and the weapons loadouts given in the gamebooks to determine and rank the best combination of assets to use against a particular target type. This would reduce the work required to create the packages and be of tremendous help to players who are not tactically proficient.

A second project would be determining the optimal placement of tanker assets to meet the ATO that the optimization model produces.

APPENDIX A. GAMS CODE AND DATAFILE

This appendix contains the GAMS source code and the sample datafile for an 8 period ATO required by the enhanced ATO Optimization Model.

```
$TITLE  Naval Postgraduate School
$ENHANCED AIR TASKING ORDER OPTIMIZATION MODEL
$STITLE    ATOFIX1    (ver. 94/07/10)
$offupper offsymxref offsymlist offuellist inlinecom { }
$ontext
       25 AUG 94   K CRAWFORD

$offtext
options
   limrow     =    0
   limcol     =    0
   solprint   =    on
   mip        =    xa
   rmip       =    xa
   optcr      =    0.25  {<<< optimality tolerance: values
                           closer to zero may give better
                           solutions but will take longer}
   iterlim    =    5000000
   reslim     =    150000   {maximum solve time in seconds}
   ;

SETS
   A    assets
   I    sites
   J    targets
   N    strike packages
   M    mission types
   TYPE  target type
   K     coordinates
   T     time
   POT   period on top
   ;

$INCLUDE A:\ATO.DAT
$INCLUDE ATO.DIS
```

```
PARAMETERS
QTY(a,j,n)    quantity of asset a in strike package n on
               target j
EPREF(j,n)    effectiveness-based preference of strike package
USED(a,j)     checks if asset is potentially  used against
              target
DPEN(a,i,j) Penalty for travel distance
JMAP(j,m)     Mapping parameter
TPREF(j)      Target Preference of target j
ST(j)         On station time required at target j
OST(a,i,j)    On station time req. of asset a launching from i
              striking j{ new parameter required to make ST(j)
                     compatable with CT(a,i,j)}
CT(a,i,j)   Total mission time in periods
             {includes on station time}
FOT(a,i,j)  Fly out time in periods ;

QTY(a,j,n)  = SUM(m $TYPE(j,m),STRIKEDATA(m,n,a,"QUANTITY"));

EPREF(j,n)  = SUM(m $ TYPE(j,m), SMAX( a,
                 STRIKEDATA(m,n,a,"PREFERENCE")));

USED(a,j)   = SUM(m $ TYPE(j,m), SUM( n ,
                 STRIKEDATA(m,n,a,"QUANTITY")) );

DPEN(a,i,j)$(AVAIL(i,a) and USED(a,j) and(DIST(i,j) LE
             RANGE(a))) =  m1*((DIST(i,j)/RANGE(a)) );

DPEN(a,i,j)$(AVAIL(i,a) and USED(a,j) and(DIST(i,j) GE
             RANGE(a))) = ceil  ((DIST(i,j)-RANGE(a))/
             RANGE(a)) + m2*((DIST(i,j)-RANGE(a))/RANGE(a));

CT(a,i,j)$(AVAIL(i,a) and USED(a,j))
           = ceil((((2*DIST(i,j))/SPEED(a))+(ST(j)/60))/ph)  ;

FOT(a,i,j)$(AVAIL(i,a) and USED(a,j))
           = round((DIST(i,j)/SPEED(a))/ph);

ST(j) = round(    (ST(j)/60)/ph     );

* Check CT-ST.  If odd then ST = ST + 1 and FOT = (CT-ST)/2
* define OST for a,i,j, combinations

OST(a,i,j)  $((CT(a,i,j)$(AVAIL(i,a) and USED(a,j)))) =ST(j);

OST(a,i,j)  $((CT(a,i,j)$(AVAIL(i,a) and USED(a,j))) and
            ( mod( CT(a,i,j) - st(j) , 2) eq 1 )) = st(j)+1 ;
* redefine FOT
FOT(a,i,j)$((CT(a,i,j)$(AVAIL(i,a) and USED(a,j))) and
            ( mod( CT(a,i,j) - st(j) , 2) eq 1 ))
            = (CT(a,i,j) - OST(a,i,j))/2;
```

```
BINARY VARIABLES
  X(j,n,t)  Strike package n assigned to target j arriving
            on top in t
  Y(a,i,j)  Site i authorized to provide asset a to target j
   ;



POSITIVE VARIABLES
  E(j)           Elastic variable for not striking target
  Z(a,i,j,t)     Quantity of asset a allocated from site i to
                 target j launching in period t
  QL(a,i,t)      Quantity of asset a at site i at the end of
                 period t   ;

FREE VARIABLE
  OBJ        Objective variable
  ;

EQUATIONS
  STRIKE(j)        Strike each target with exactly one package
  DEMAND(a,j,t)    Meet demand for assets at each target
  SINGLE(a,j)      Use single site as source of each asset for
                   each target
  SUPPLY(a,i,t)    Observe asset availability at sites
  LOGICAL(a,i,j,t)   Variable upper bound relating Y and Z
  OBJDEF
  ;

* * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
STRIKE(j)..

      SUM((n,t) $ EPREF(j,n),

      X(j,n,t) $ POT(j,t) )  +  E(j)   =E=  1 ;

* * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
DEMAND(a,j,t) $ (USED(a,j)$POT(j,t)) ..

      SUM(i $(AVAIL(i,a) and (Dist(i,j) LE MAXFILLS(a)*
              RANGE(a))), Z(a,i,j,t-FOT(a,i,j)))

      =E=

      SUM(n,QTY(a,j,n) * X(j,n,t) ) ;

* * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
```

```
{A single launch site is used for all aircraft types.  The
 only exception are tankers.  Tankers may come from any
 launch source}

SINGLE(a,j) $( USED(a,j)and (GIVE(a) eq 0)) ..

      SUM(i $ (AVAIL(i,a) and (Dist(i,j) LE
          MAXFILLS(a)*RANGE(a))) , Y(a,i,j) )

      =L= 1 ;
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
SUPPLY(a,i,t) $ AVAIL(i,a) ..

SUM(j $(USED(a,j) and (Dist(i,j) LE MAXFILLS(a)*RANGE(a))),

        Z(a,i,j,t) $ POT(j,t+FOT(a,i,j))) + QL(a,i,t)

        =E=

        QL(a,i,t-1) +

        SUM (j $ (POT(j,t-(OST(a,i,j)+ FOT(a,i,j)))),
             Z(a,i,j,t-CT(a,i,j))) +

        AVAIL(i,a)$(ORD(t) eq 1);

* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
LOGICAL(a,i,j,t) $(((AVAIL(i,a) AND USED(a,j) and

                    (Dist(i,j) LE MAXFILLS(a)*RANGE(a)) ))

                    $ POT(j,t+FOT(a,i,j)))..

           Z(a,i,j,t)

           =L=

           AVAIL(i,a) * Y(a,i,j) ;

* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
OBJDEF..

   XSCALE * SUM( (j,n,t) $POT(j,t), EPREF(j,n) * X(j,n,t) )

   - ESCALE * SUM( j, TPREF(j)*EPEN(j) * E(j) )

   - DSCALE * SUM((a,i,j) $(AVAIL(i,a) AND USED(a,j)
                 and (Dist(i,j) LE MAXFILLS(a)*RANGE(a))),
                 DPEN(a,i,j) * Y(a,i,j) )
   =E=  OBJ ;
```

```
MODEL  ATO  /ALL/ ;
SOLVE  ATO  USING  MIP  MAXIMIZING  OBJ ;

FILE F1  /A:\VBIN.OUT/;
FILE F2 /A:\ato.out/;
PUT F1 ;
LOOP((j,a,i,t) $ Z(a,i,j,t),
     put j.TL:11,",", i.TL:11,",", z.L(a,i,j,t):3:0,",",
         a.TL:11,",", TIME(j):4:0,DIST(i,j)/;

             );

Put F2;

if ( sum(j,e.L(j)) gt 0.01,
     put "    THE FOLLOWING TARGETS WERE NOT ASSIGNED"/
     put " "/
LOOP(j $ E.L(j),
     put j.TL:11/;
     put ""/;
            );
else
     put "    ALL TARGETS WERE ASSIGNED" / ) ;

put/;
put/;

PUT F2;
PUT "                          END OF PERIOD INVENTORY";
PUT "                    ";
loop(t, put t.tl:5);
put /;

loop(i,
      put i.TL:15/;
      loop(a$AVAIL(i,a),
            put a.TL @16:11

     loop(t,
            put QL.L(a,i,t):5:0;

                          );
   put/;       );
  put/;  );

DISPLAY DIST
DISPLAY CT, FOT, OST;
DISPLAY  X.L, Z.L, QL.L ;
```

ATO.DAT FILE

```
  SETS
A   assets
/
A-10
A-6
B-1
F-117
F-14
F-15
F-18
KC-10
E-2
E-3A
F-111
EA-6B
THAWK
/

I    sites
/
CV-65
Airbase-01
Airbase-02
AIRBASE-03
AIRBASE-04
MAG-01
SSN-69
/

J   targets
/
T-02
T-04
T-06
T-07
T-08
T-09
EYE-1
C-1
C-2
C-3
TEXACO-A
T-01
T-03
T-10
T-11
T-12
T-13
T-15
T-16
T-14
```

```
T-17
T-18
T-19
T-20
T-21
T-22
T-24
T-25
T-26
T-27
T-28
T-29
T-30
T-31
T-32
T-33
T-34
/
M  mission type(target type)
/
SAM
AFL
AFS
BLDG
HBUNK
AEW
TANKER
CAP-1A
CAP-1B
CAP-1C
ROAD-BRDG
TLAM
POL
EW-NITE
CAS
/
Type  (J,M)
/
T-02        .BLDG
T-04        .HBUNK
T-06        .AFL
T-07        .AFL
T-08        .SAM
T-09        .AFS
EYE-1       .AEW
C-1         .CAP-1A
C-2         .CAP-1A
C-3         .CAP-1A
TEXACO-A    .TANKER
T-01        .AFL
T-03        .AFS
T-10        .BLDG
T-11        .HBUNK
T-12        .POL
```

```
T-13        .ROAD-BRDG
T-15        .POL
T-16        .BLDG
T-14        .TLAM
T-17        .EW-NITE
T-18        .ROAD-BRDG
T-19        .AFS
T-20        .BLDG
T-21        .EW-NITE
T-22        .POL
T-24        .POL
T-25        .HBUNK
T-26        .ROAD-BRDG
T-27        .ROAD-BRDG
T-28        .TLAM
T-29        .SAM
T-30        .EW-NITE
T-31        .CAS
T-32        .CAS
T-33        .CAS
T-34        .CAS
/
T     time periods
/ T1*T8  /
N     strike packages
/  PACKAGE-1*PACKAGE-3  /
 POT (j,t) time period assigned to target
 /
T-02         .  T3
T-04         .  T4
T-06         .  T6
T-07         .  T4
T-08         .  T7
T-09         .  T5
EYE-1        .  T3
C-1          .  T3
C-2          .  T3
C-3          .  T4
TEXACO-A     .  T3
T-01         .  T3
T-03         .  T3
T-10         .  T4
T-11         .  T6
T-12         .  T6
T-13         .  T4
T-15         .  T5
T-16         .  T3
T-14         .  T4
T-17         .  T8
T-18         .  T6
T-19         .  T6
T-20         .  T5
T-21         .  T8
T-22         .  T4
```

```
T-24          .  T4
T-25          .  T5
T-26          .  T7
T-27          .  T5
T-28          .  T2
T-29          .  T7
T-30          .  T1
T-31          .  T1
T-32          .  T2
T-33          .  T3
T-34          .  T4
/  ;
TABLE   STRIKEDATA(m,n,a,*)
                                                    PREFERENCE    QUANTITY

SAM            . Package-1 .   F-18     2              2
SAM            . Package-2 .   F-15     2              3
SAM            . Package-3 .   A-6      2              5
SAM            . Package-3 .   EA-6B    1
AFL            . Package-1 .   A-6      4              5
AFL            . Package-1 .   F-14     4
AFL            . Package-2 .   F-18     4              3
AFL            . Package-3 .   F-15     4              4
AFS            . Package-1 .   A-6      2              5
AFS            . Package-2 .   F-15     2              3
AFS            . Package-3 .   F-14     2              2
BLDG           . Package-1 .   A-6      2              4
BLDG           . Package-2 .   F-111    2              5
BLDG           . Package-3 .   F-18     2              3
HBUNK          . Package-1 .   A-6      4              5
HBUNK          . Package-1 .   F-14     2
HBUNK          . Package-2 .   F-15     4              5
HBUNK          . Package-3 .   F-18     4              4
AEW            . Package-1 .   E-3A     1              5
TANKER         . Package-1 .   KC-10    1              5
CAP-1A         . Package-1 .   F-14     2              5
CAP-1B         . Package-1 .   F-14     2              5
CAP-1B         . Package-2 .   F-18     2              4
ROAD-BRDG      . Package-1 .   F-18     2              5
ROAD-BRDG      . Package-2 .   F-14     2              4
ROAD-BRDG      . Package-3 .   F-15     2              5
TLAM           . Package-1 .   THAWK    2              5
POL            . Package-1 .   A-6      2              5
POL            . Package-2 .   F-15     2              4
EW-NITE        . Package-1 .   F-117    1              5
EW-NITE        . Package-2 .   A-6      2              4
CAS            . Package-1 .   A-10     4              5
CAS            . Package-2 .   F-18     4              4
 ;
Parameter Time (J)      time on top
/
T-02          0800
T-04          1045
T-06          1530
```

```
T-07          1030
T-08          2030
T-09          1425
EYE-1         0630
C-1           0700
C-2           0900
C-3           1100
TEXACO-A      0630
T-01          0720
T-03          0800
T-10          0920
T-11          1615
T-12          1715
T-13          1045
T-15          1220
T-16          0829
T-14          1130
T-17          2215
T-18          1600
T-19          1530
T-20          1340
T-21          2245
T-22          0940
T-24          1130
T-25          1440
T-26          1920
T-27          1215
T-28          0500
T-29          1805
T-30          0230
T-31          0300
T-32          0500
T-33          0800
T-34          1000
/ ;
Parameter TPREF (J)
/
T-02          1
T-04          3
T-06          2
T-07          1
T-08          2
T-09          1
EYE-1         1
C-1           1
C-2           1
C-3           1
TEXACO-A      1
T-01          2
T-03          1
T-10          2
T-11          3
T-12          1
T-13          2
```

```
T-15          1
T-16          2
T-14          1
T-17          2
T-18          1
T-19          2
T-20          3
T-21          2
T-22          1
T-24          1
T-25          2
T-26          3
T-27          1
T-28          2
T-29          1
T-30          2
T-31          1
T-32          1
T-33          1
T-34          1
/ ;
Parameter RANGE (a)
/
A-10                500
A-6                 600
B-1                 1500
F-117               600
F-14                600
F-15                650
F-18                450
KC-10               2000
E-2                 800
E-3A                1000
F-111               650
EA-6B               500
THAWK               1000
/ ;
Parameter SPEED (a)
/
A-10                300
A-6                 450
B-1                 1000
F-117               550
F-14                600
F-15                600
F-18                500
KC-10               300
E-2                 300
E-3A                300
F-111               500
EA-6B               500
THAWK               300
/ ;
```

```
Parameter FILL (a)
/
A-10            2
A-6             2
B-1             2
F-117           2
F-14            2
F-15            2
F-18            2
F-111           2
EA-6B           2
/ ;
PARAMETER GIVE (a)
/
A-10            0
A-6             0
B-1             0
F-117           0
F-14            0
F-15            0
F-18            0
KC-10           0
E-2             0
E-3A            0
F-111           0
EA-6B           0
THAWK           0
/ ;
PARAMETER MAXFILLS (a)
/
A-10            1
A-6             3
B-1             2
F-117           3
F-14            3
F-15            3
F-18            3
KC-10           1
E-2             1
E-3A            1
F-111           3
EA-6B           3
THAWK           1
/ ;
 TABLE LOC(i,*)
                LAT-DEG   LAT-MIN   LONG-DEG   LONG-MIN
CV-65             30        30        110        30
Airbase-01        32        38        119        36
Airbase-02        33        46        110        46
AIRBASE-03        32        06        115        34
AIRBASE-04        35        00         95        43
MAG-01            35        05        110        48
SSN-69            30        35        110        30
```

```
TABLE COORD(j,*)
                    LAT-DEG   LAT-MIN   LONG-DEG   LONG-MIN
T-02                  43        03        115        30
T-04                  41        00        101        32
T-06                  39        06        104        17
T-07                  40        46        107        16
T-08                  44        44        114        44
T-09                  38        38        115        55
EYE-1                 31        31        109        29
C-1                   33        33        110        00
C-2                   33        33        110        00
C-3                   33        33        110        00
TEXACO-A              32        06        102        33
T-01                  40        29        117        05
T-03                  42        04        97         31
T-10                  40        32        117        15
T-11                  41        00        116        45
T-12                  40        44        117        31
T-13                  39        25        117        03
T-15                  40        12        115        45
T-16                  41        00        116        43
T-14                  39        55        116        32
T-17                  40        21        116        45
T-18                  39        52        116        54
T-19                  39        35        116        41
T-20                  39        17        111        32
T-21                  38        45        116        45
T-22                  40        25        116        45
T-24                  41        00        116        24
T-25                  39        56        111        34
T-26                  39        24        116        45
T-27                  39        12        116        30
T-28                  40        13        116        29
T-29                  40        12        115        56
T-30                  41        00        117        00
T-31                  37        00        110        00
T-32                  37        05        117        15
T-33                  37        00        109        45
T-34                  37        03        110        10
 ;

PARAMETER AVAIL (i,a)
/
CV-65                . A-6              12
CV-65                . F-18             20
CV-65                . F-14             12
CV-65                . E-2              3
CV-65                . EA-6B            4
Airbase-01           . F-117            10
Airbase-02           . F-15             20
Airbase-02           . F-111            10
AIRBASE-03           . KC-10            6
AIRBASE-04           . E-3A             4
MAG-01               . F-18             12
```

```
MAG-01               . A-10              12
SSN-69               . THAWK             12
/ ;

PARAMETER ST (j)
/
EYE-1             360
C-1               120
C-2               120
C-3               120
TEXACO-A          480
T-31              30
T-32              30
T-33              30
T-34              30
/ ;
PARAMETER EPEN(J) elastic penalty for not striking target j;
EPEN(J) = 100  ;
PARAMETER XSCALE  Objective function scale factor for
                  strike preference  ;
XSCALE = 1  ;
PARAMETER ESCALE  Objective function scale factor for
                  elastic penalties  ;
ESCALE = 1  ;
PARAMETER DSCALE  Objective function scale factor for strike
                  distance  ;
DSCALE = 1  ;
SCALARS
m1   short range slope      /.5/
m2   long range slope       /.7/
ph                          / 3   /   ;
```

APPENDIX B. SAMPLE DATAFILES

This appendix contains printouts of the sample datafiles created by the interface designed for this thesis.

ASSET DATABASE

NAME	COMBAT RADIUS	SPEED	TAKE	GIVE	# IFR
A-10	500	300	2,000	0	0
A-6	600	450	2,000	0	3
B-1	1,500	1,000	2,000	0	2
F-117	600	550	2,000	0	3
F-14	600	600	2,000	0	3
F-15	650	600	2,000	0	3
F-18	450	500	2,000	0	3
KC-10	2,000	300		100,000	0
E-2	800	300		0	0
E-3A	1,000	300		0	0
F-111	650	500	2,000	0	3
EA-6B	500	500	2,000	0	3
THAWK	1,000	300		0	0

HITLIST DATABASE

TARGET ID	TOT	PREFERENCE
T-02	0800	1
T-04	1045	3
T-06	1530	2
T-07	1030	1
T-08	2030	2
T-09	1425	1
EYE-1	0630	1
C-1	0700	1
C-2	0900	1
C-3	1100	1
TEXACO-A	0630	1

TARGET ID	TOT	PREFERENCE
T-01	0720	2
T-03	0800	1
T-10	0920	2
T-11	1615	3
T-12	1715	1
T-13	1045	2
T-15	1220	1
T-16	0829	2
T-14	1130	1
T-17	2215	2
T-18	1600	1
T-19	1530	2
T-20	1340	3
T-21	2245	2
T-22	0940	1
T-24	1130	1
T-25	1440	2
T-26	1920	3
T-27	1215	1
T-28	0500	2
T-29	1805	1
T-30	0230	2
T-31	0300	1
T-32	0500	1
T-33	0800	1
T-34	1000	1

LAUNCH SITE DATABASE

SITE NAME	LATITUDE	LONGITUDE	ASSETS	#
CV-65	30 30	110 30	A-6	12
			F-18	20
			F-14	12
			E-2	3
			EA-6B	4
Airbase-01	32 38	119 36	F-117	10
Airbase-02	33 46	110 46	F-15	20
			F-111	10
AIRBASE-03	32 06	115 34	KC-10	6
AIRBASE-04	35 00	095 43	E-3A	4
MAG-01	35 05	110 48	F-18	12
			A-10	12
SSN-69	30 35	110 30	THAWK	12

STRIKE PACKAGES DATABASE

TARGET TYPE	PACKAGE #	ASSET	QUANTITY	PREF
SAM	Package-1	F-18	2	2
	Package-2	F-15	2	3
	Package-3	A-6	2	5
		EA-6B	1	
AFL	Package-1	A-6	4	5
		F-14	4	
	Package-2	F-18	4	3
	Package-3	F-15	4	4
AFS	Package-1	A-6	2	5
	Package-2	F-15	2	3
	Package-3	F-14	2	
BLDG	Package-1	A-6	2	4
	Package-2	F-111	2	5
	Package-3	F-18	2	3
HBUNK	Package-1	A-6	4	5
		F-14	2	
	Package-2	F-15	4	5
	Package-3	F-18	4	4
AEW	Package-1	E-3A	1	5
TANKER	Package-1	KC-10	1	5
CAP-1A	Package-1	F-14	2	5
CAP-1B	Package-1	F-14	2	5
	Package-2	F-18	2	4
ROAD-BRDG	Package-1	F-18	2	5
	Package-2	F-14	2	4
	Package-3	F-15	2	5
TLAM	Package-1	THAWK	2	5
POL	Package-1	A-6	2	5
	Package-2	F-15	2	4
EW-NITE	Package-1	F-117	1	5
	Package-2	A-6	2	4
CAS	Package-1	A-10	4	5
	Package-2	F-18	4	4

TARGET DATABASE

NAME	ID	LATITUDE	LONGITUDE	TARGET TYPE	ON STATION TIME
	T-01	40 29	117 05	AFL	0
	T-02	43 03	115 30	BLDG	0
	T-03	42 04	097 31	AFS	0
T-04	T-04	41 00	101 32	HBUNK	0
	TEXACO-A	32 06	102 33	TANKER	480
	TEXACO-B	27 03	103 32	TANKER	480
	T-06	39 06	104 17	AFL	0
	T-07	40 46	107 16	AFL	0
	T-08	44 44	114 44	SAM	0
	T-09	38 38	115 55	AFS	0
	EYE-1	31 31	109 29	AEW	360
	C-1	33 33	110 00	CAP-1A	120
	C-2	33 33	110 00	CAP-1A	120
	C-3	33 33	110 00	CAP-1A	120
	C-4	33 33	110 00	CAP-1A	120
	CAP 2A	33 00	095 00	CAP-1C	120
	T-10	40 32	117 15	BLDG	0
	T-12	40 44	117 31	POL	0
	T-13	39 25	117 03	ROAD-BRDG	0
	T-14	39 55	116 32	TLAM	0
	T-15	40 12	115 45	POL	0
	T-16	41 00	116 43	BLDG	0
	T-17	40 21	116 45	EW-NITE	0
	T-18	39 52	116 54	ROAD-BRDG	0
	T-19	39 35	116 41	AFS	0
	T-20	39 17	111 32	BLDG	0
	T-21	38 45	116 45	EW-NITE	0
	T-22	40 25	116 45	POL	0
	T-24	41 00	116 24	POL	0
	T-25	39 56	111 34	HBUNK	0
	T-26	39 24	116 45	ROAD-BRDG	0
	T-27	39 12	116 30	ROAD-BRDG	0
	T-28	40 13	116 29	TLAM	0
	T-29	40 12	115 56	SAM	0
	T-30	41 00	117 00	EW-NITE	0
	T-31	37 00	110 00	CAS	30
	T-32	37 05	117 15	CAS	30
	T-33	37 00	109 45	CAS	30
	T-34	37 03	110 10	CAS	30

APPENDIX C. FLIGHT SCHEDULES AND ATO INFORMATION FILE

This appendix contains the flight schedules and ATO Information file created with the 8 period dataset.

FLIGHT SCHEDULE BY LAUNCH TIME

Launch Site	Asset	#	Target ID	Time onTop	Launch Time	Target Lat/Long
AIRBASE-01	F-117	1	T-30	0230	0125	41 00 117 00
	F-117	1	T-17	2215	2114	40 21 116 45
	F-117	1	T-21	2245	2156	38 45 116 45
AIRBASE-02	F-15	4	T-01	0720	0622	40 29 117 05
	F-111	2	T-02	0800	0637	43 03 115 30
	F-111	2	T-16	0829	0717	41 00 116 43
	F-111	2	T-10	0920	0809	40 32 117 15
	F-15	4	T-04	1045	0934	41 00 101 32
	F-15	4	T-07	1030	0938	40 46 107 16
	F-15	2	T-13	1045	0953	39 25 117 03
	F-15	2	T-24	1130	1031	41 00 116 24
	F-15	2	T-27	1215	1126	39 12 116 30
	F-111	2	T-20	1340	1254	39 17 111 32
	F-15	4	T-25	1440	1357	39 56 111 34
	F-15	4	T-06	1530	1438	39 06 104 17
	F-15	2	T-18	1600	1506	39 52 116 54
	F-15	2	T-12	1715	1614	40 44 117 31
	F-15	4	T-11	1615	1615	41 00 116 45
AIRBASE-03	KC-10	1	TEXACO-A	0630	0358	32 06 102 33
AIRBASE-04	E-3A	1	EYE-1	0630	0344	31 31 109 29
CV-65	A-6	2	T-03	0800	0537	42 04 97 31
	F-14	2	C-1	0700	0639	33 33 110 00
	A-6	2	T-22	0940	0757	40 25 116 45
	F-14	2	C-2	0900	0839	33 33 110 00
	F-14	2	C-3	1100	1039	33 33 110 00
	A-6	2	T-15	1220	1042	40 12 115 45
	A-6	2	T-09	1425	1300	38 38 115 55

	A-6	2	T-19	1530	1354	39 35 116 41
	A-6	2	T-29	1805	1627	40 12 115 56
	EA-6B	1	T-29	1805	1637	40 12 115 56
	A-6	2	T-08	2030	1815	44 44 114 44
	EA-6B	1	T-08	2030	1829	44 44 114 44
MAG-01	A-10	4	T-31	0300	0232	37 00 110 00
	A-10	4	T-32	0500	0343	37 05 117 15
	A-10	4	T-33	0800	0731	37 00 109 45
	A-10	4	T-34	1000	0932	37 03 110 10
	F-18	2	T-26	1920	1827	39 24 116 45
SSN-69	THAWK	2	T-28	0500	0231	40 13 116 29
	THAWK	2	T-14	1130	0904	39 55 116 32

FLIGHT SCHEDULE BY TIME ON TARGET

LAUNCH SITE	ASSET	#	TARGET ID	TIME ON TOP	LAUNCH TIME	TARGET LAT/LONG
AIRBASE-01	F-117	1	T-30	0230	0125	41 00 117 00
	F-117	1	T-17	2215	2114	40 21 116 45
	F-117	1	T-21	2245	2156	38 45 116 45
AIRBASE-02	F-15	4	T-01	0720	0622	40 29 117 05
	F-111	2	T-02	0800	0651	43 03 115 30
	F-111	2	T-16	0829	0829	41 00 116 43
	F-111	2	T-10	0920	0821	40 32 117 15
	F-15	4	T-07	1030	0938	40 46 107 16
	F-15	4	T-04	1045	0934	41 00 101 32
	F-15	2	T-13	1045	0953	39 25 117 03
	F-15	2	T-24	1130	1031	41 00 116 24
	F-15	2	T-27	1215	1126	39 12 116 30
	F-111	2	T-20	1340	1302	39 17 111 32
	F-15	4	T-25	1440	1357	39 56 111 34
	F-15	4	T-06	1530	1438	39 06 104 17
	F-15	2	T-18	1600	1506	39 52 116 54
	F-15	4	T-11	1615	1615	41 00 116 45
	F-15	2	T-12	1715	1614	40 44 117 31
AIRBASE-03	KC-10	1	TEXACO-A	0630	0358	32 06 102 33
AIRBASE-04	E-3A	1	EYE-1	0630	0344	31 31 109 29
CV-65	F-14	2	C-1	0700	0639	33 33 110 00
	A-6	2	T-03	0800	0612	42 04 97 31
	F-14	2	C-2	0900	0839	33 33 110 00

	A-6	2	T-22	0940	0823	40 25 116 45
	F-14	2	C-3	1100	1039	33 33 110 00
	A-6	2	T-15	1220	1107	40 12 115 45
	A-6	2	T-09	1425	1321	38 38 115 55
	A-6	2	T-19	1530	1418	39 35 116 41
	EA-6B	1	T-29	1805	1651	40 12 115 56
	A-6	2	T-29	1805	1651	40 12 115 56
	EA-6B	1	T-08	2030	1849	44 44 114 44
	A-6	2	T-08	2030	1849	44 44 114 44
MAG-01	A-10	4	T-31	0300	0232	37 00 110 00
	A-10	4	T-32	0500	0343	37 05 117 15
	A-10	4	T-33	0800	0731	37 00 109 45
	A-10	4	T-34	1000	0932	37 03 110 10
	F-18	2	T-26	1920	1751	39 24 116 45
SSN-69	THAWK	2	T-28	0500	0231	40 13 116 29
	THAWK	2	T-14	1130	0904	39 55 116 32

FLIGHT SCHEDULE BY TARGET

TARGET	LAUNCH SITE	ASSET	#	TIME on TARGET
C-1	CV-65	F-14	2	0700
C-2	CV-65	F-14	2	0900
C-3	CV-65	F-14	2	1100
EYE-1	AIRBASE-04	E-3A	1	0630
T-01	AIRBASE-02	F-15	4	0720
T-02	AIRBASE-02	F-111	2	0800
T-03	CV-65	A-6	2	0800
T-04	AIRBASE-02	F-15	4	1045
T-06	AIRBASE-02	F-15	4	1530
T-07	AIRBASE-02	F-15	4	1030
T-08	CV-65	A-6	2	2030
	CV-65	EA-6B	1	2030
T-09	CV-65	A-6	2	1425
T-10	AIRBASE-02	F-111	2	0920
T-11	AIRBASE-02	F-15	4	1615
T-12	AIRBASE-02	F-15	2	1715
T-13	AIRBASE-02	F-15	2	1045
T-14	SSN-69	THAWK	2	1130
T-15	CV-65	A-6	2	1220
T-16	AIRBASE-02	F-111	2	0829
T-17	AIRBASE-01	F-117	1	2215
T-18	AIRBASE-02	F-15	2	1600
T-19	CV-65	A-6	2	1530
T-20	AIRBASE-02	F-111	2	1340
T-21	AIRBASE-01	F-117	1	2245
T-22	CV-65	A-6	2	0940

T-24	AIRBASE-02	F-15	2	1130
T-25	AIRBASE-02	F-15	4	1440
T-26	MAG-01	F-18	2	1920
T-27	AIRBASE-02	F-15	2	1215
T-28	SSN-69	THAWK	2	0500
T-29	CV-65	A-6	2	1805
	CV-65	EA-6B	1	1805
T-30	AIRBASE-01	F-117	1	0230
T-31	MAG-01	A-10	4	0300
T-32	MAG-01	A-10	4	0500
T-33	MAG-01	A-10	4	0800
T-34	MAG-01	A-10	4	1000
TEXACO-A	AIRBASE-03	KC-10	1	0630

ATO INFORMATION

ALL TARGETS WERE ASSIGNED

END OF PERIOD INVENTORY

	T1	T2	T3	T4	T5	T6	T7	T8
CV-65								
A-6	12	10	8	8	6	6	8	12
F-14	12	12	8	10	12	12	12	12
F-18	20	20	20	20	20	20	20	20
E-2	3	3	3	3	3	3	3	3
EA-6B	4	4	4	4	4	3	2	4
AIRBASE-01								
F-117	9	10	10	10	10	10	10	8
AIRBASE-02								
F-15	20	20	16	8	14	8	20	20
F-111	10	10	6	8	8	10	10	10
AIRBASE-03								
KC-10	6	5	5	5	5	5	6	6
AIRBASE-04								
E-3A	4	3	3	3	3	4	4	4
MAG-01								
A-10	8	8	4	4	8	8	8	8
F-18	12	12	12	12	12	12	10	12
SSN-69								
THAWK	10	10	10	10	12	12	12	12

LAUNCH SITE	ASSET	#
AIRBASE-01	F-117	3
AIRBASE-02	F-111	8
	F-15	34
AIRBASE-03	KC-10	1
AIRBASE-04	E-3A	1
CV-65	A-6	14
	EA-6B	2
	F-14	6
MAG-01	A-10	16
	F-18	2
SSN-69	THAWK	4

TOTAL SORTIES FLOWN = 91

ESTIMATED GAS (in pounds) REQUIRED FOR AIR REFUELING 46000

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